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CMS Group Physics Topics and Strategy

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Fermilab Physics Advisory Committee

June 24, 2015

Outline

- Overview of Fermilab CMS group
- General Analysis Strategy
- Physics Highlights from Run 1
- Preparation for Run 2
- Physics Strategy at the start of Run 2
- Summary

Fermilab CMS Group

- Fermilab is the largest US group and the second largest group overall in CMS
- In 2015 we have 55 CMS authors (+ 5 emeritus), including 16 postdocs (1 Lederman Fellow), 2 Wilson Fellows

- Fermilab scientists are active in many activities:
  - Analysis of CMS Data
  - Startup of Run 2
  - Building Phase-1 Upgrades
  - R&D for Phase-2 Upgrades
  - Software and Computing (Host of US Tier-1)

LHC Physics Center at Fermilab - LPC

- As the host lab for CMS in the US, Fermilab hosts the LPC, founded in 2004 as a regional center for CMS
- Serves as a resource and physics analysis hub, housed on 10th and 11th floors of Wilson Hall
  - Proximity to a broad range of CMS expertise
  - Access to Fermilab resources
  - Connection to Fermilab theorists
- The LPC hosts activities for members of CMS and the wider LHC community, including ATLAS and theorists
- Attracts key scientists to spend time at LPC through Distinguished Researcher and Guest&Visitor programs

- Many scientists contribute to facilitating physics with LPC residents
- Many analysis collaborations are formed among the LPC residents and their institutions

General Strategy for Analysis (1)

- **Work on the most interesting topics at the energy frontier**
  - P5 Science Drivers:
    - Higgs as a new tool for discovery
    - Explore the unknown
    - Dark Matter
  - Run 1 Analyses were well-aligned with these topics
    - Higgs
    - SUSY
    - Exotica
    - Standard Model measurements as indirect probes of new physics

General Strategy for Analysis (2)

- **Build on past experience**
  - Tevatron experience informed many Run 1 analyses
  - In Run 2, we are building on experience and success from Run 1

  - Also, leverage experience within a given physics signature
    - Key to most searches is to understand the background very well
    - In many cases, analysis groups form around a specific signature that is used to search for different types of new physics
    - This can also yield SM measurements, that in themselves are indirect probes of new physics
    - Example: Vector boson + jets group used that topology for Higgs, Exotica, and Standard Model analyses

General Strategy for Analysis (3)

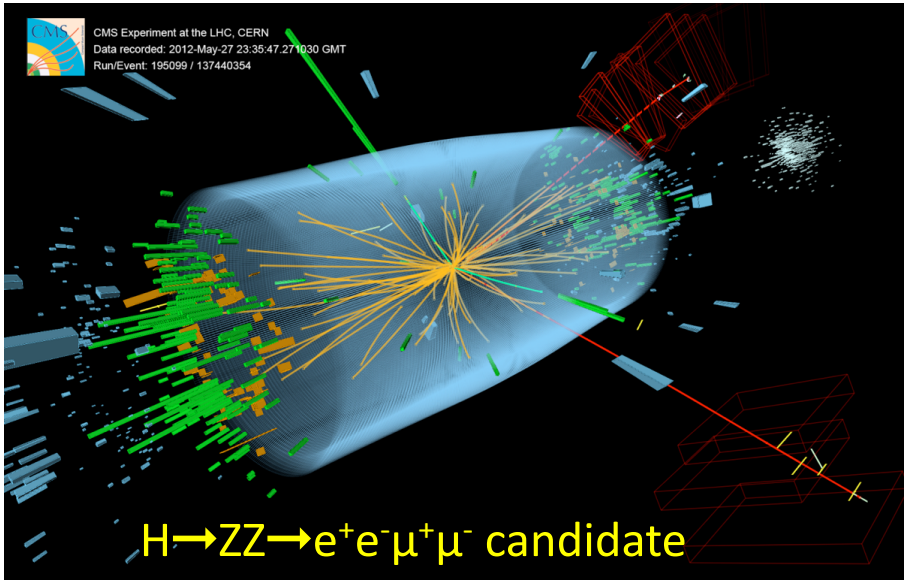
- **Put our postdocs in a position to succeed**
  - Give them visibility on important analyses
  - Make sure they are in a group with sufficient people/resources
  - Several post-docs became analysis sub-group leaders in Run 1, and this was a boost for their job search

- **Build collaborations with our US CMS colleagues**
  - Often with groups at the LPC

➡**Most of our analysis groups have several FNAL scientists and 2-3 postdocs, collaborating with similar groups at 3-4 other institutions**

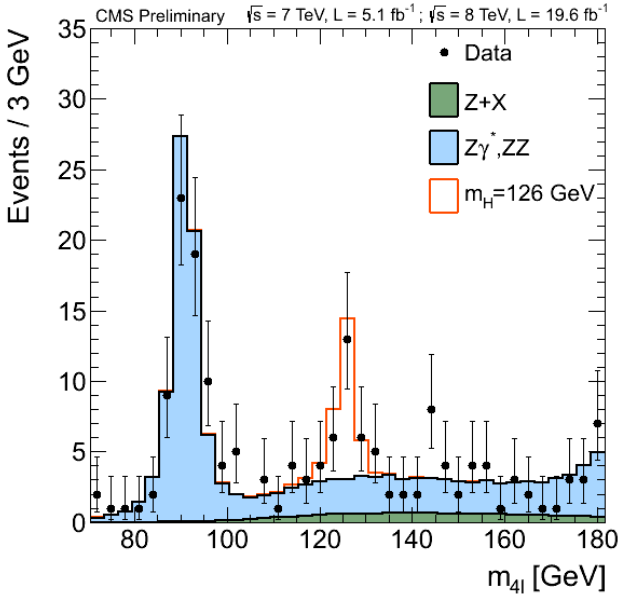
Physics in LHC Run 1

- CMS had great success in Run 1, including the discovery of the Higgs Boson together with ATLAS
- The following slides show some of the physics analyses where Fermilab scientists had a leading role

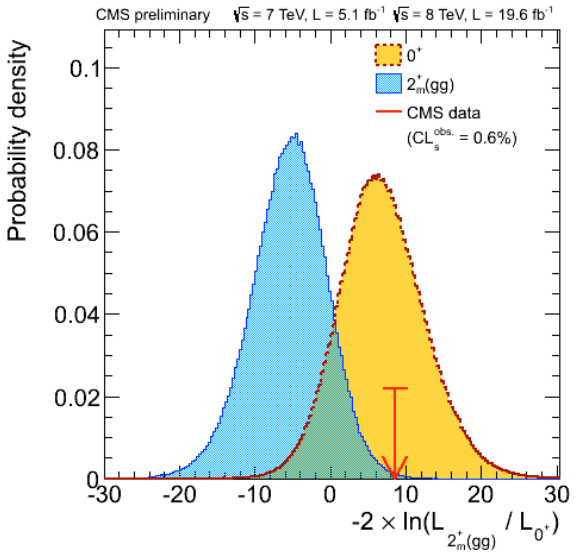


Run 1: Higgs Physics

- H→ZZ→4l
  - Implementation of kinematic discriminant to separate signal from ZZ background
  - Improved sensitivity at time of initial observation

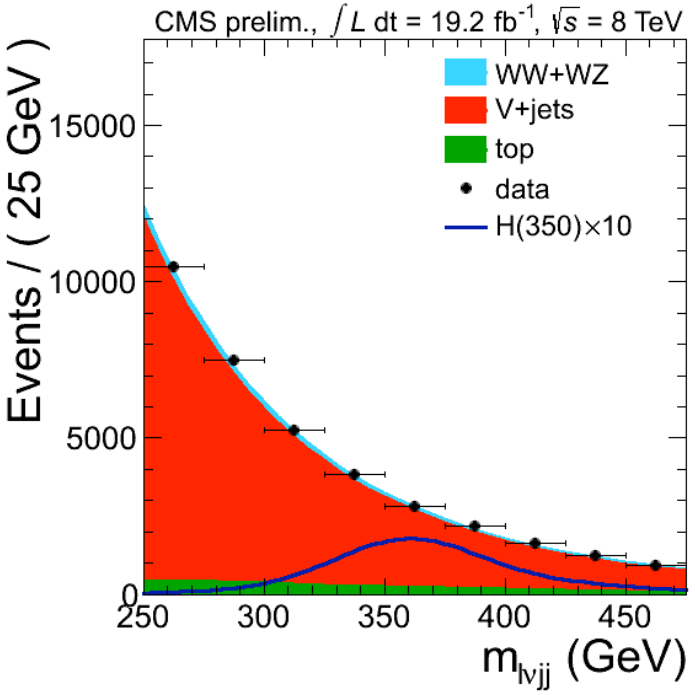


- H→WW→lvlv
  - Development of initial analysis
  - Development of 2D analysis that led to spin/parity analysis to test non-SM Higgs
  - Fermilab RA(Y. Gao) recognized with 2013 Tollestrup Award

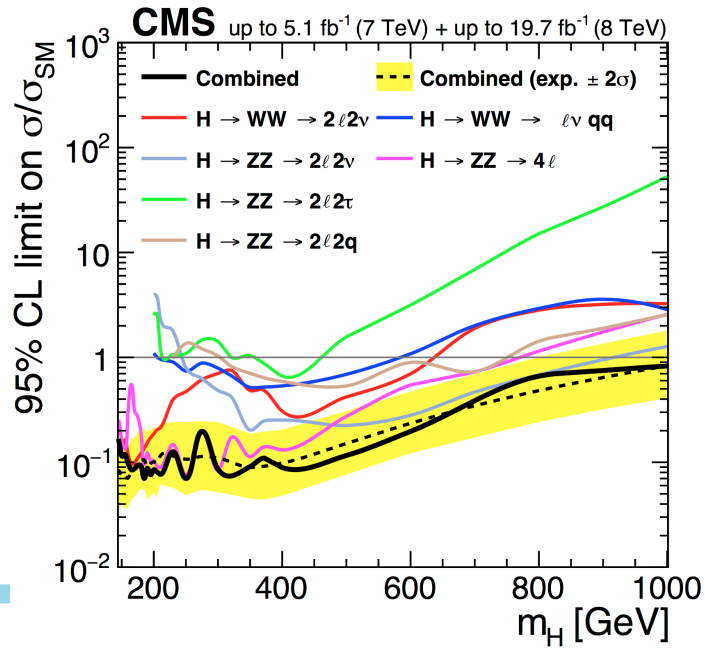


Run 1: Higgs Physics

- H→WW→lνjj
  - Incorporate boosted jet techniques in high mass Higgs search
  - same signature used to investigate CDF W+2-jet mass bump

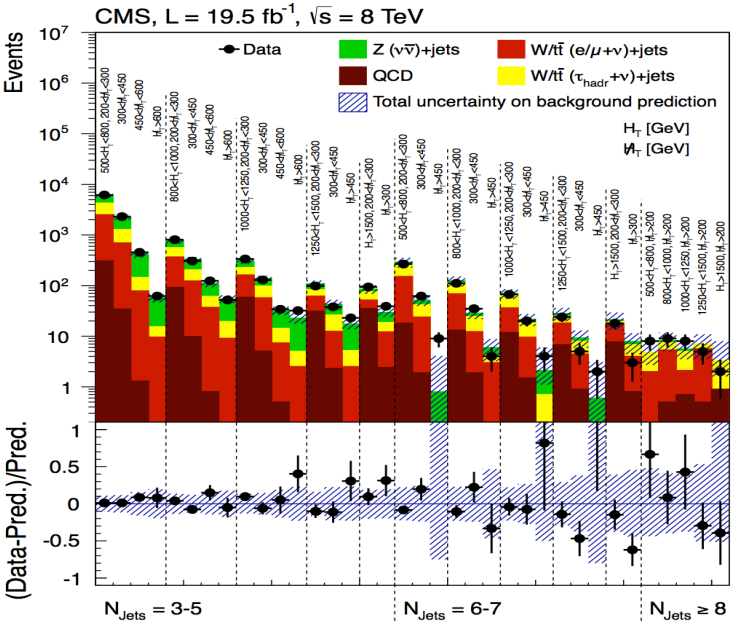


- WW, ZZ analyses combined in high mass Higgs paper

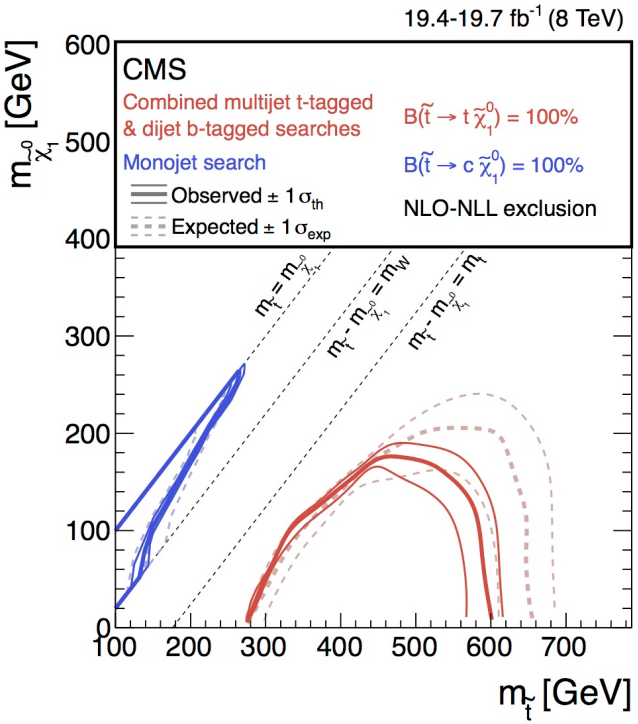


Run 1: Hadronic SUSY

- Multijet search for squarks, gluinos
  - important early SUSY search
  - extended in 8 TeV data to high jet multiplicity



- Search for direct stop production

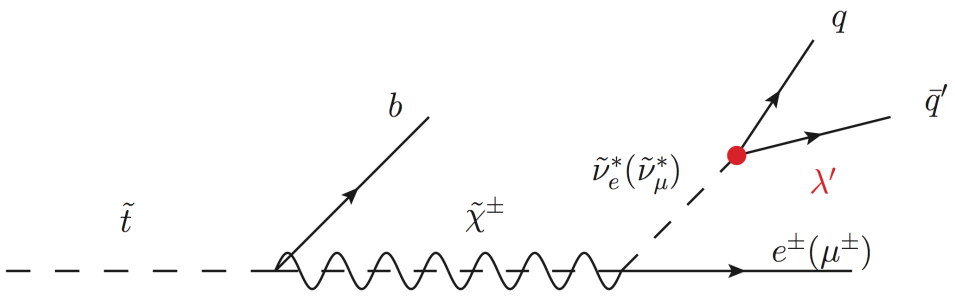


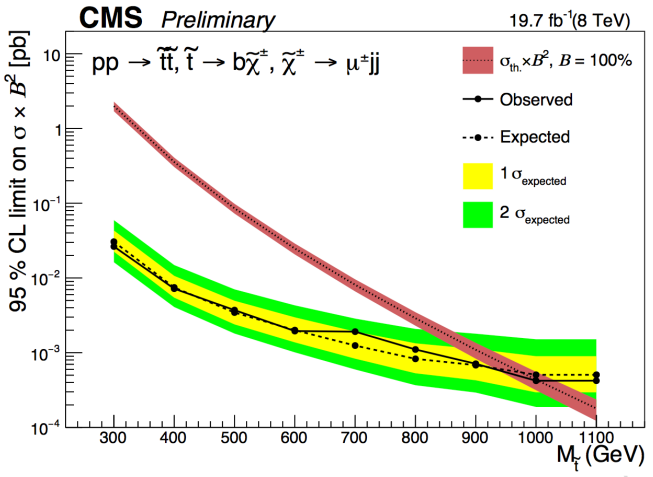
Significant LPC, US collaboration on both topics

Baylor, Carnegie-Mellon, Colorado, Florida International, Florida State, Hamburg-DESY, UI Chicago, Iowa State, Notre Dame, UC Riverside, Rutgers, Rockefeller, Virginia

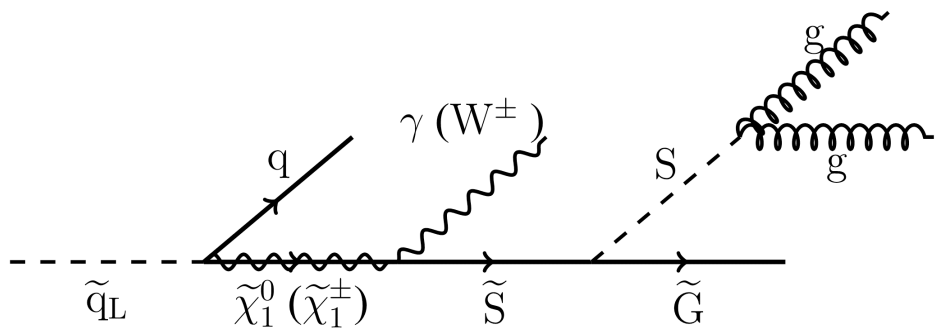
Run 1: RPV, Stealth SUSY

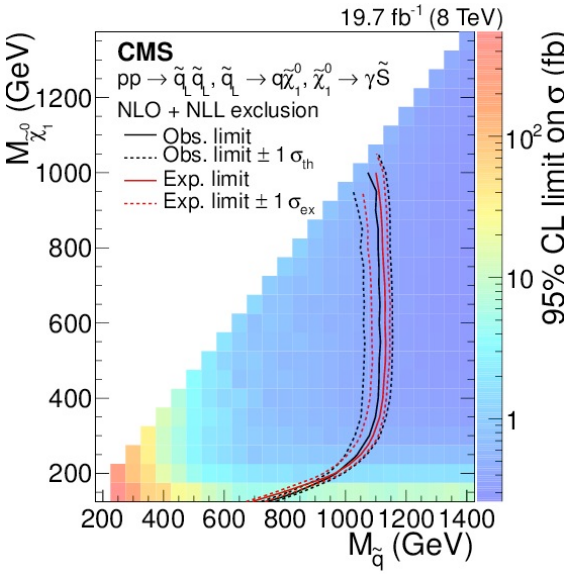
- R-Parity Violating SUSY
  - (Low missing E_T signature)





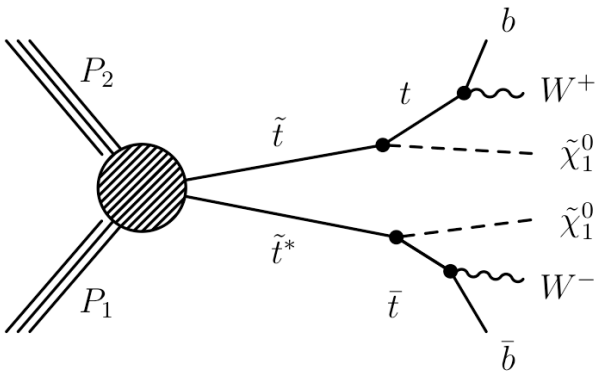
- Stealth SUSY

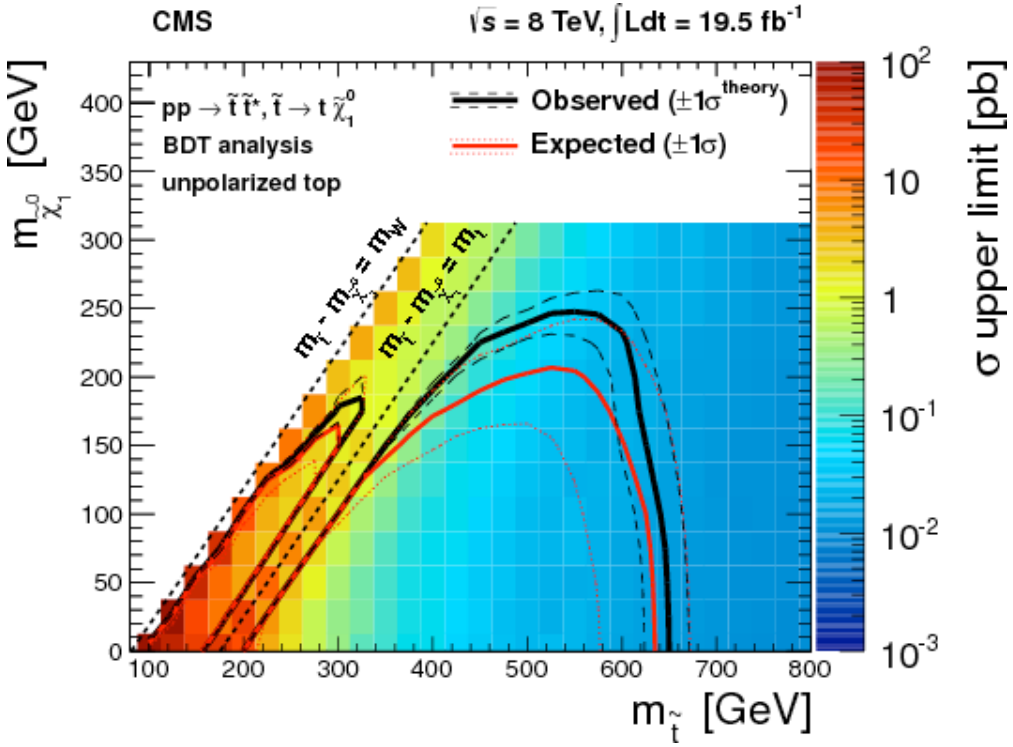




Run 1: Leptonic SUSY

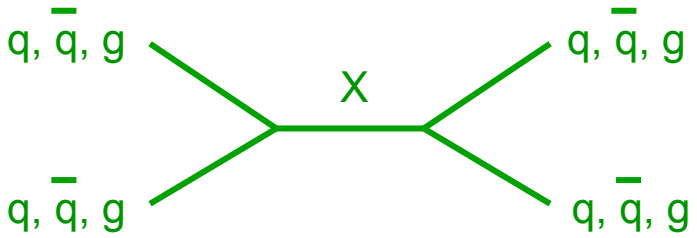
- Leptonic searches using 1- and 2-lepton final states
  - Inclusive searches with opposite charge dileptons and same charge dileptons
  - Direct stop production in single lepton final state



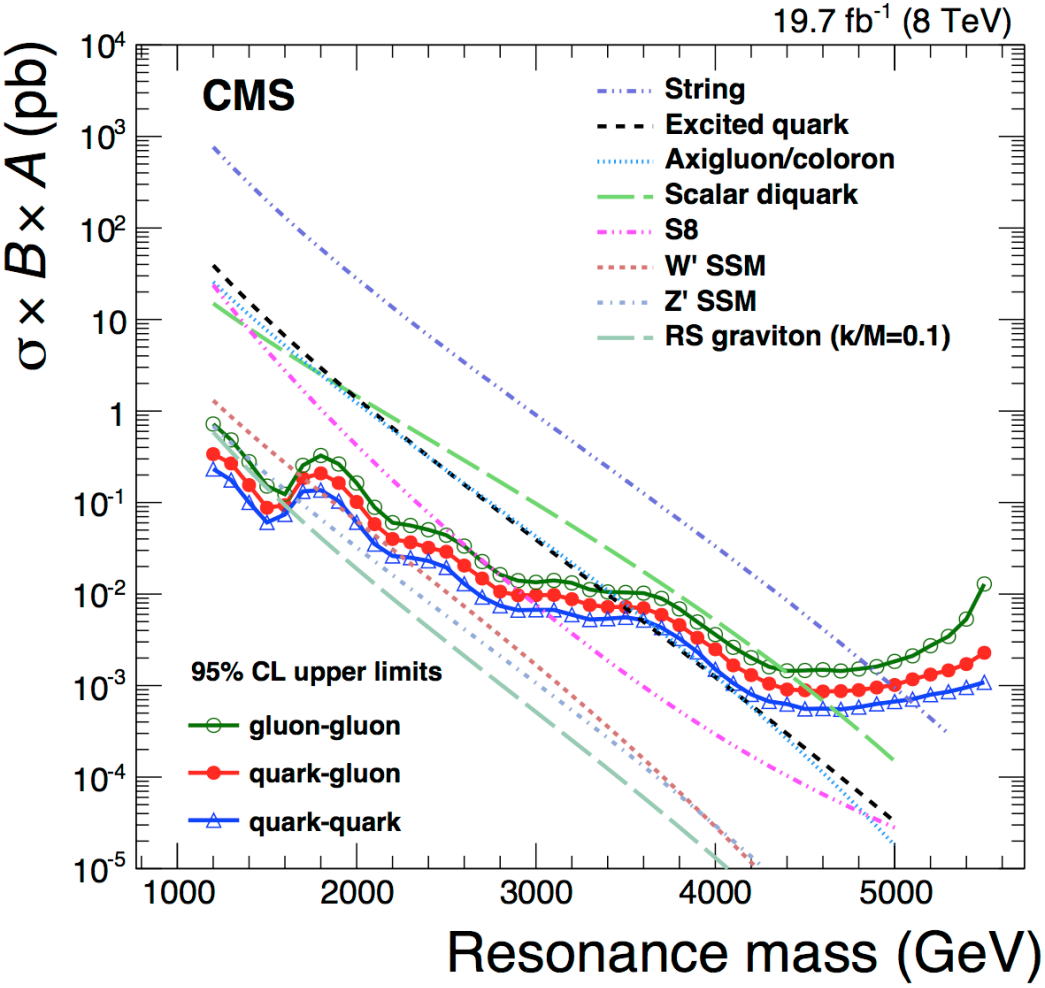


Collaborators: Aachen, DESY, ETH-Zurich, Florida, Strasbourg, UCSB, UCSD

Run 1: Exotica - Dijet Resonance Search

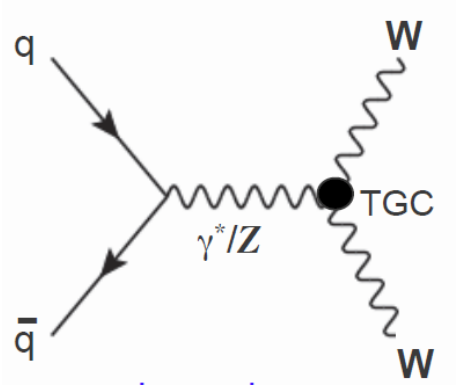


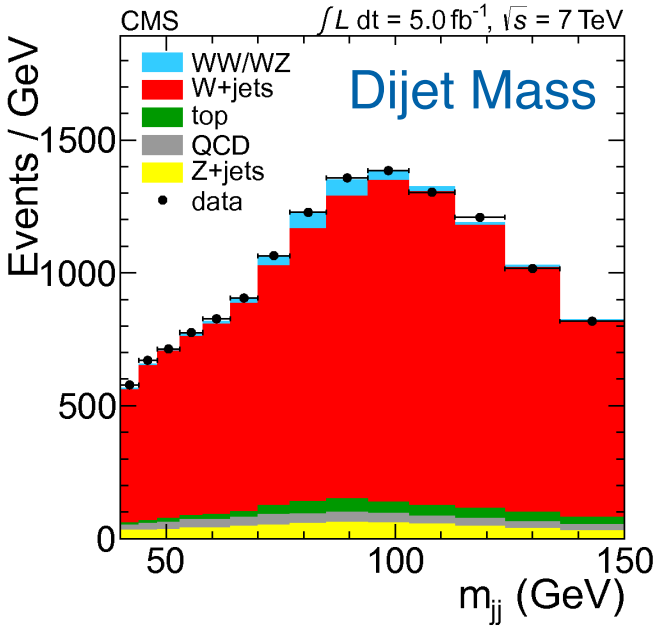
- Sensitive to a wide variety of new physics models
  - Excited Quarks
  - W', Z'
  - RS gravitons
  - …

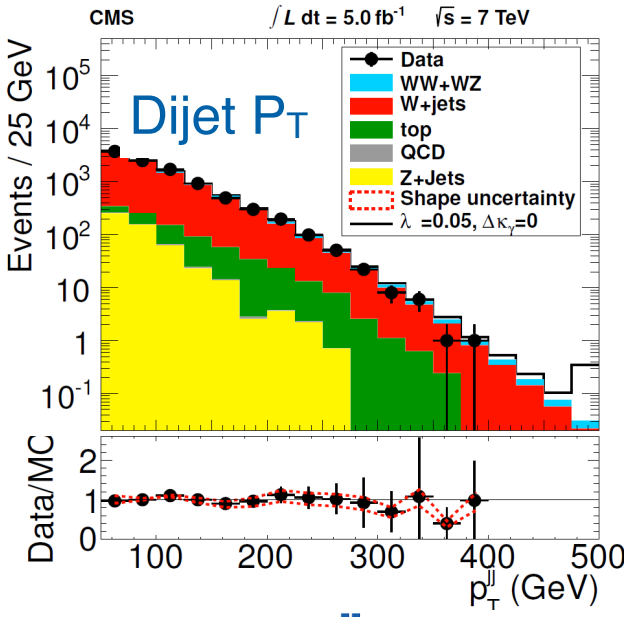


Run 1: Standard Model - Dibosons

- WW/WZ in semi-leptonic channel
  - Select W+ 2 jet events, reconstruct W or Z hadronically
  - 4.3-σ significant signal observed, first at LHC
  - Measured cross-section consistent w/SM
  - Dijet P_T is most powerful experimental constraint on TGCs to date







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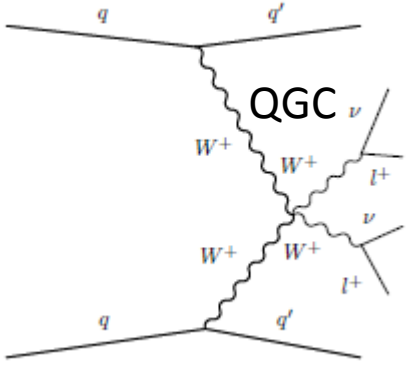
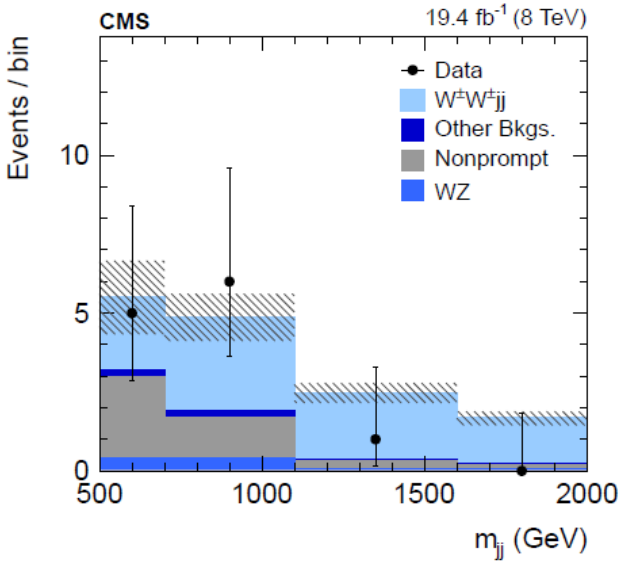
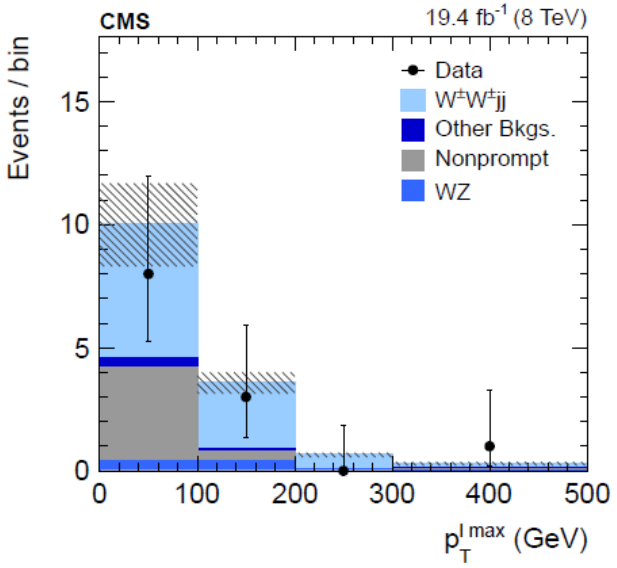
Run 1: Standard Model

- Same Sign WW scattering
  - Same-sign WW vector boson scattering production provides attractive S/B at LHC
  - Anomalous differential cross sections could indicate extended Higgs sector, new particles, or (giant) anomalous QGCs
  - 2.0 σ significant signal for VBS (3.1 σ expected); first VBS search at CMS!
  - First step in a comprehensive, long term LHC program to study vector boson scattering



Signal has large dijet mass and lepton pt





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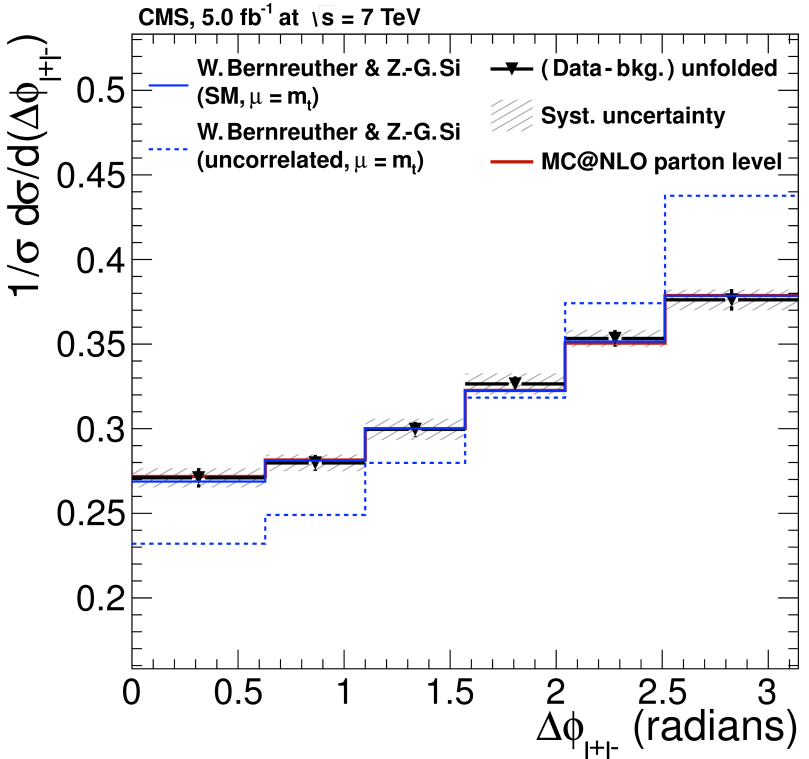
Run 1: Standard Model - top properties

- ttbar Spin Correlations
  - Exploit understanding of dilepton topology
  - Follow up on asymmetries observed at the Tevatron
  - Also measure top quark polarization and ttbar charge asymmetry

Relative enhancement at low Δϕ due to spin correlations

If ttbar was coming from stop production, top quarks would look similar to uncorrelated ttbar production

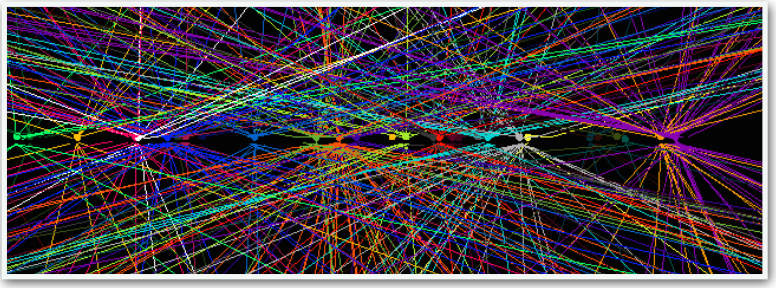


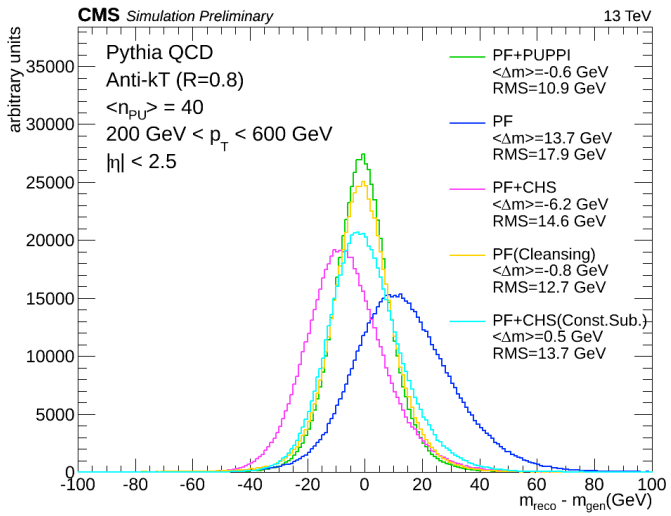
Run 1 Physics Output

- The analyses shown above are not an exhaustive list of all FNAL physics in Run 1
- As part of January institutional review, we counted the papers on which Fermilab had lead authors
- Found that Fermilab Scientists and Postdocs were leading authors on **74 physics papers** in Run 1
  - Mostly SM (primarily EWK), SUSY, Higgs, Exotica
  - At the time, ~350 papers from CMS in Run 1 (now ~400)

Preparing for Physics in Run 2

- Higher pileup expected in Run 2 (and Run 3, HL-LHC)
- New tools developed to improve pileup treatment
  - coherent, **per particle**, treatment of pileup improves performance of all CMS reconstruction [PUPPI]





Pileup Per Particle Identification

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[b] *CERN, European Organization for Nuclear Research, Geneva, Switzerland*
[c] *Enrico Fermi Institute and Kavli Institute for Cosmological Physics, University of Chicago, Chicago, IL 60637, USA*
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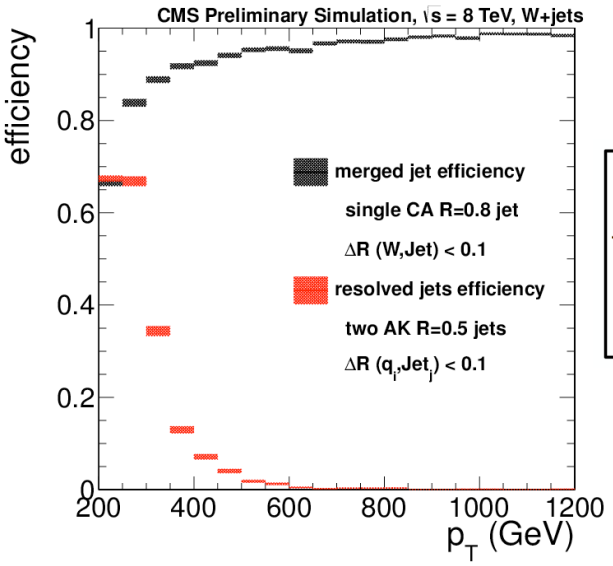
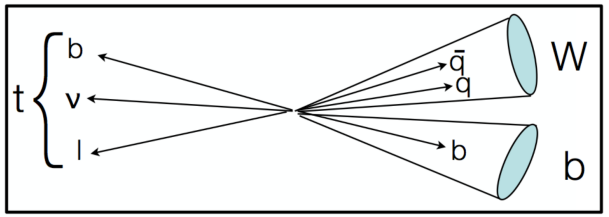
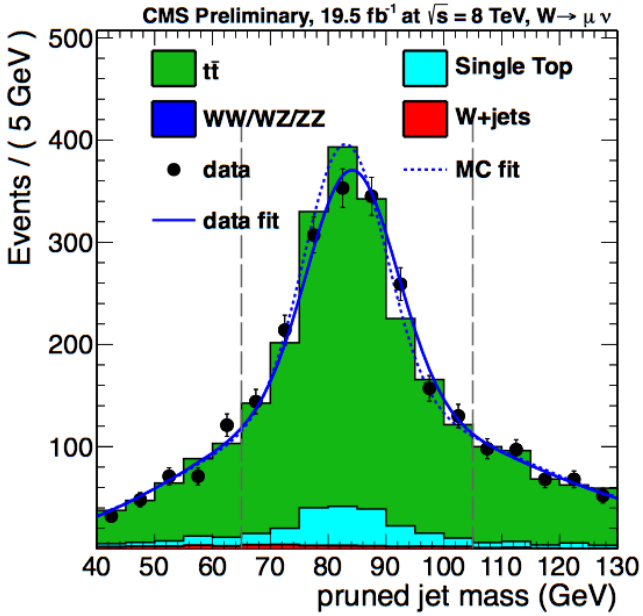
Abstract: We propose a new method for pileup mitigation by implementing "pileup per particle identification" (PUPPI). For each particle we first define a local shape α which probes the collinear versus soft diffuse structure in the neighborhood of the particle. The former is indicative of particles originating from the hard scatter and the latter of particles originating from pileup interactions. The distribution of α for charged pileup, assumed as a proxy for all pileup, is used on an event-by-event basis to calculate a weight for each particle. The weights describe the degree to which particles are pileup-like and are used to rescale their four-momenta, superseding the need for jet-based corrections. Furthermore, the algorithm flexibly allows combination with other, possibly experimental, probabilistic information associated with particles such as vertexing and timing performance. We demonstrate the algorithm improves over existing methods by looking at jet p_T and jet mass. We also find an improvement on non-jet quantities like missing transverse energy.

Preparing for Physics in Run 2

- As we go to higher energies, and search for higher mass objects, boosted jet techniques become more important
  - decay products of top, W, Higgs may be in a single merged jet
- Jet substructure tools implemented in CMS software to identify the decays of massive boosted objects
- Will be critical for searches in Run 2



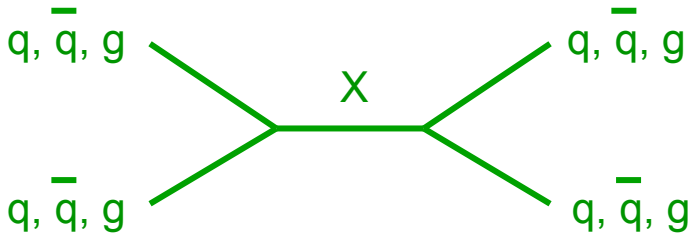




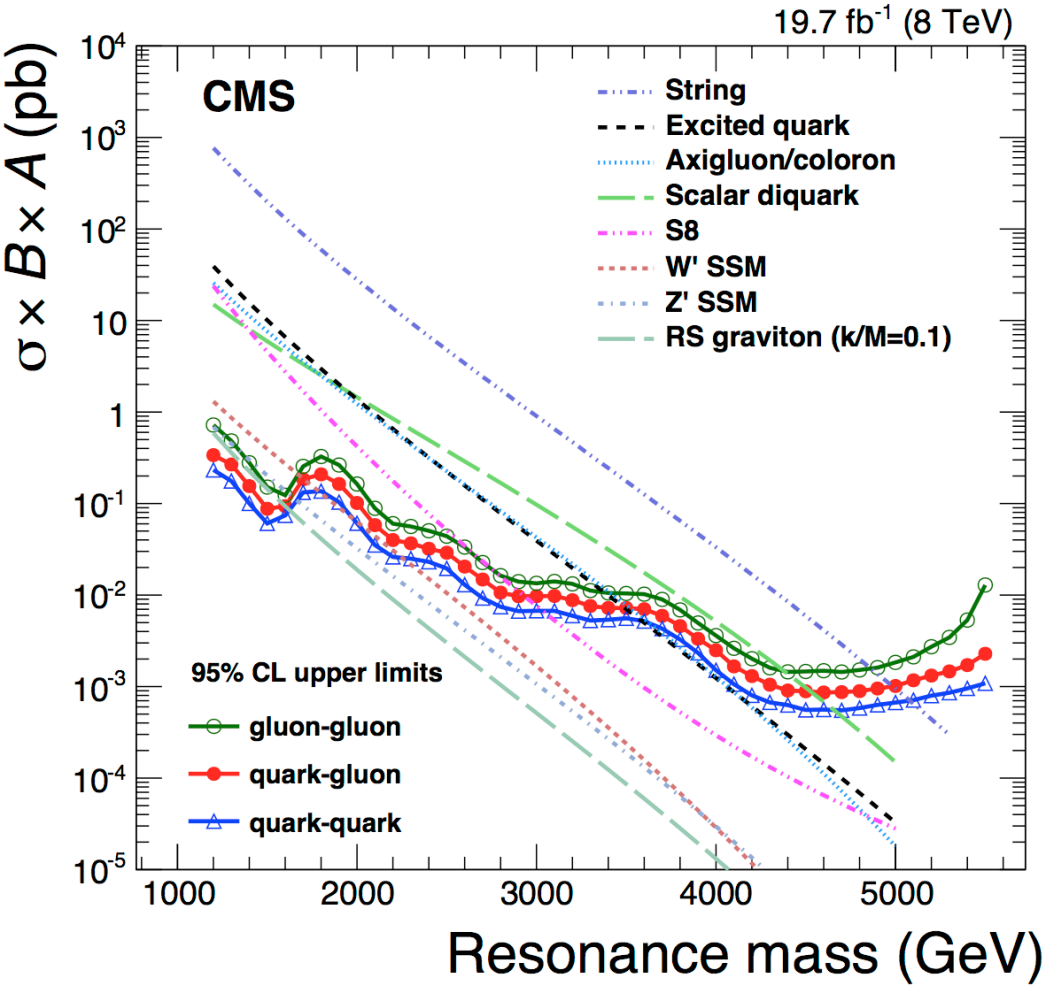
Physics Plan for Early Run 2

- In the very first data, there will be emphasis on resonances accessible with the increase in energy ⇒ Dijet resonances
- With a few fb^{-1}, we can probe new parameter space in SUSY
  - First inclusive searches, then more targeted searches
- We plan to continue our successful SUSY efforts from the past
  - Specifically, inclusive multi-jets search, opposite-sign dileptons, and stop searches in both all-hadronic and single lepton
  - "Teams" have changed, with younger people taking new roles, and some new collaborating institutions
  - Analyses have been improved, including the use of boosted jet techniques
- We will pursue some SM analyses that benefit from higher energy
  - e.g., aTGC
- H→bb, and later with full Run 2 data, measurements of Higgs couplings

Run 2: Dijet Resonance Search



- Analysis is ready to go
  - tested on 13 TeV simulation
  - analyzed first ~150 pb^{-1} of data at 13 TeV
- **With 1 fb^{-1} we can already go well beyond the limits from Run 1**



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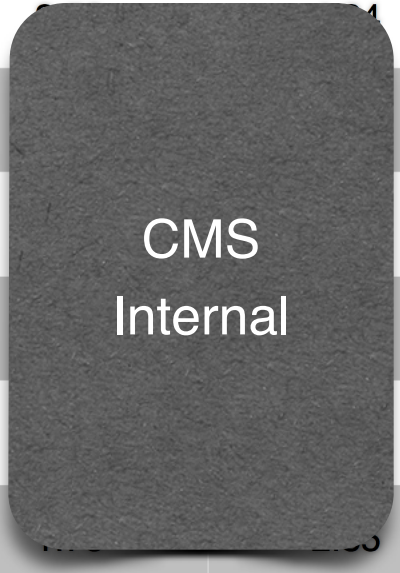
Run 2: SUSY - inclusive searches

- Inclusive SUSY search in multijets and missing energy
  - Key early SUSY analysis
  - Re-optimized for Run 2 and combined with analysis including b-tagged jets to improve sensitivity
  - Already surpassing Run 1 sensitivity with only 3 fb^{-1}

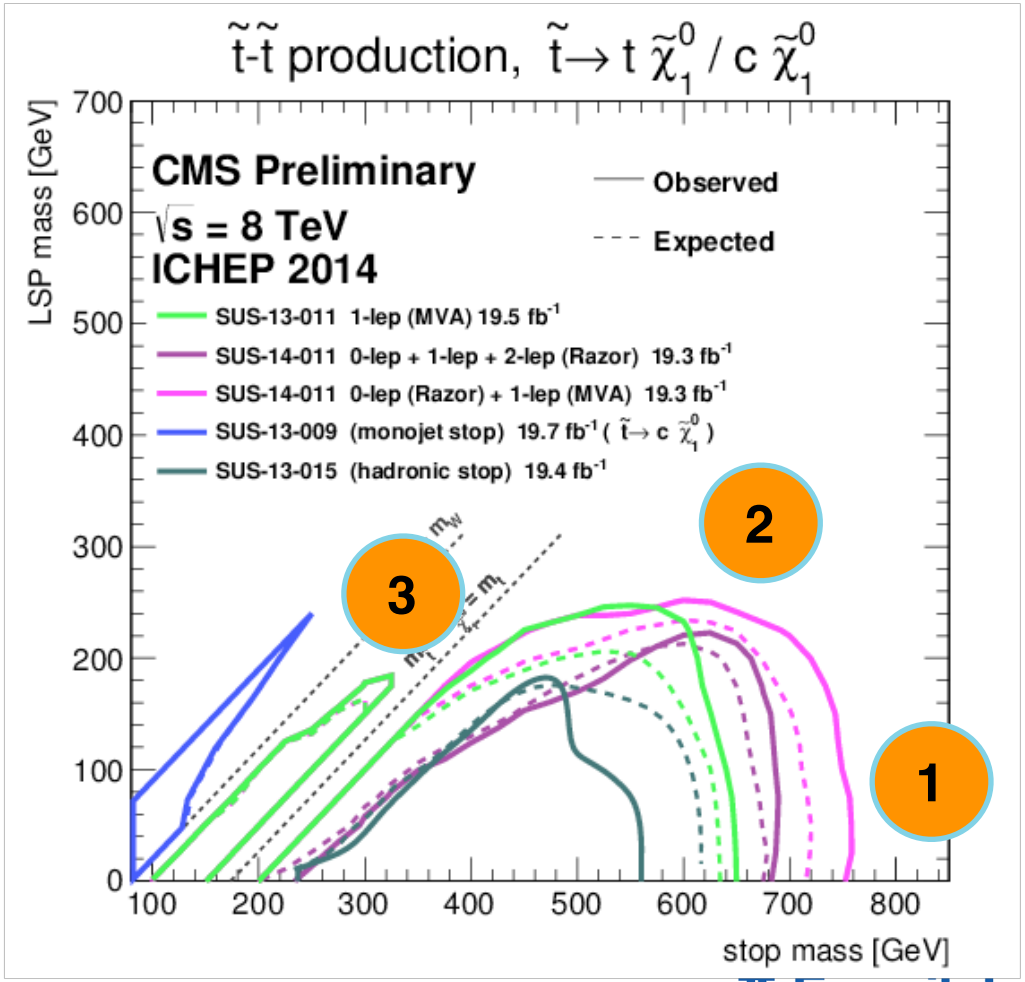
Discovery sensitivity	3 fb-1 (sigma)	10 fb-1 (sigma)
T1qqqq(1400,100)		
T1qqqq(1000,900)		
T1bbbb(1500,100)		
T1bbbb(1000,800)		
T1tttt(1500,100)		
T1tttt(1200,800)		



Run 2: SUSY - stop searches

"The LPC has the potential to be the center of gravity for the stop-pair search"

- Follow up on Run 1 in pursuing stop searches in both leptonic and hadronic channels
  1. Use boosted jets to push limits at high m_{stop}
  2. Reoptimized analysis for larger m_{stop}, m_{LSP}
  3. New approaches for compressed spectra



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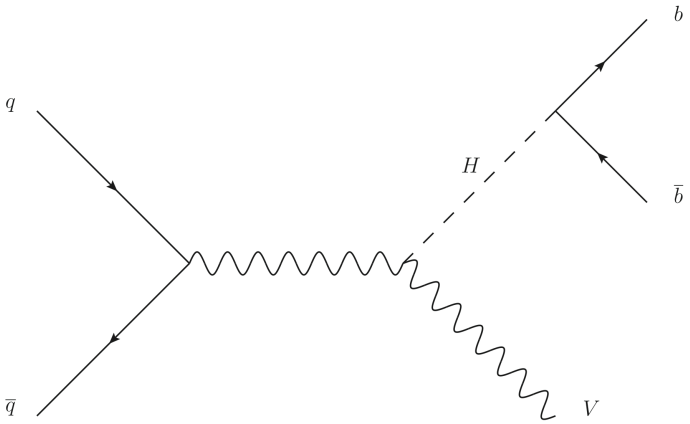
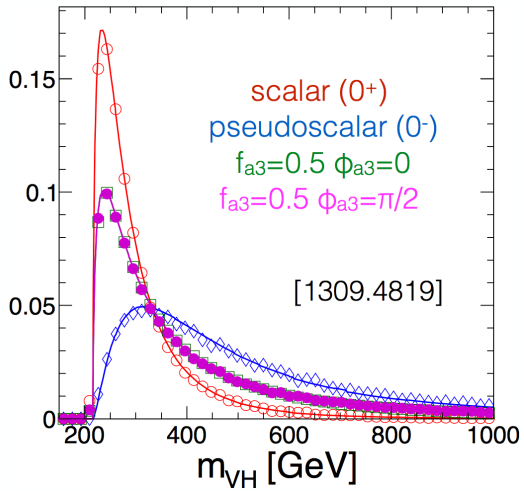
Run 2: Higgs

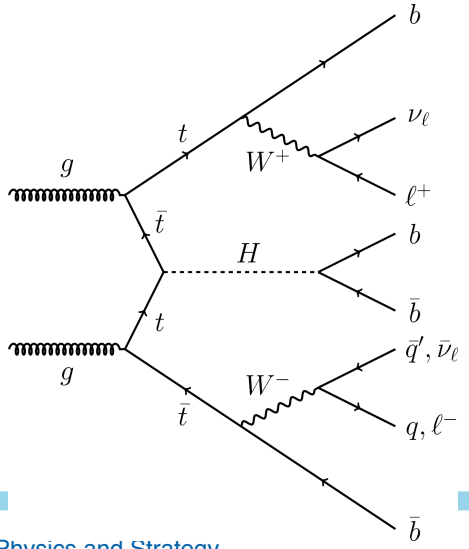
One primary focus of Higgs analysis in Run 2 will be measurements of couplings to fermions

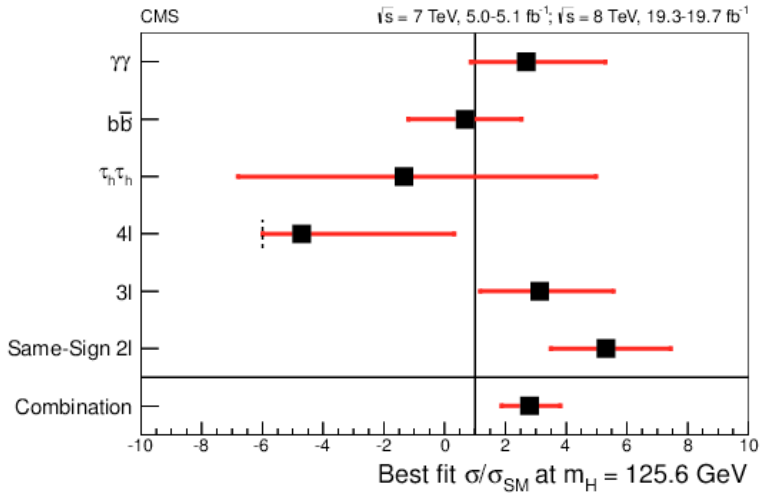
VH, H→bb





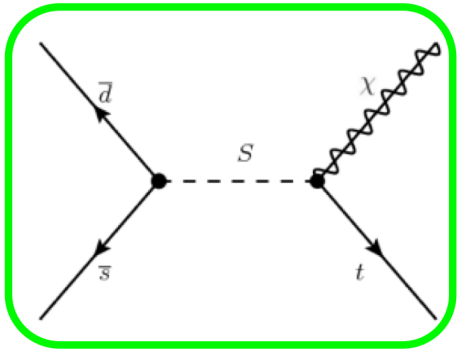
ttH, H→bb



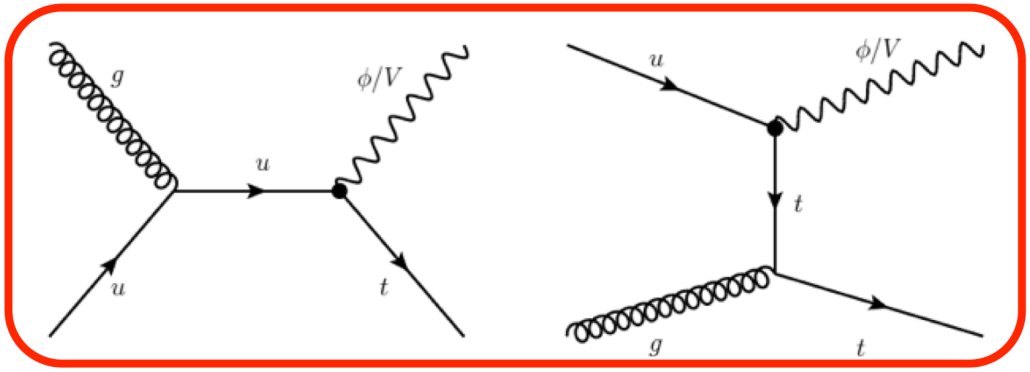


Run 2: Dark Matter — mono-Top

- New effort from FNAL
- Four scientists involved
- Part of a suite of mono-X analyses being pursued by CMS



Resonant



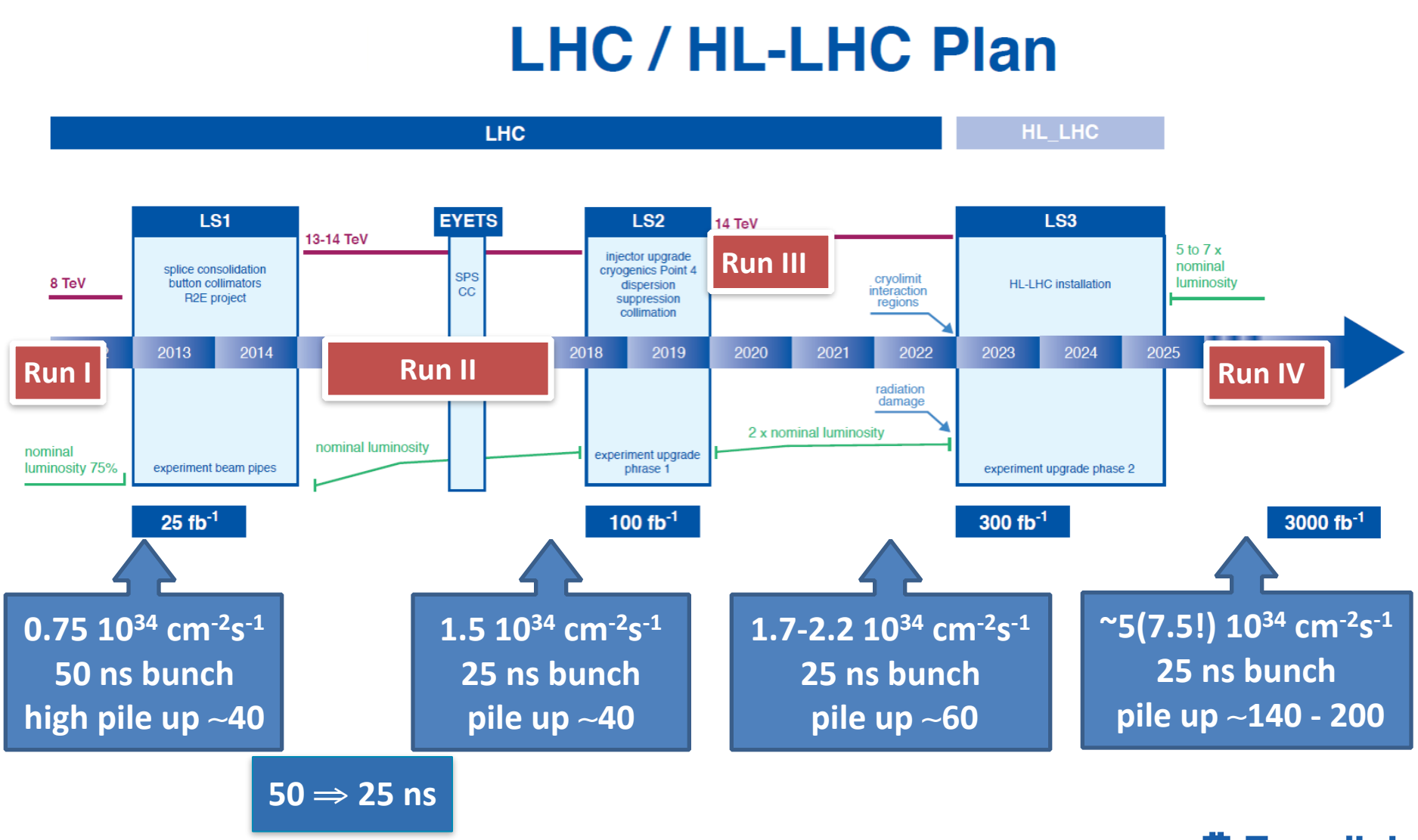
Non-Resonant

Summary

- The FNAL/CMS physics strategy is to work on important topics, building on our experience, putting our postdocs in a position to succeed, and collaborating with USCMS
- This has been successful in Run 1, with our group making significant contributions to Higgs, SUSY, Exotica, and SM Physics
- In Run 2, we are involved in many of the high profile analyses, including the dijet resonance search, both inclusive and exclusive SUSY searches, and $H \rightarrow bb$
- We have consolidated effort on the early searches, and will later pursue related analyses, once the early searches are complete
- Run 2 promises to produce exciting physics results, and we will be a big part of it

BACKUP MATERIAL

LHC: the plan


LHC / HL-LHC Plan
LHC
HL_LHC
LS1
splice consolidation
button collimators
R2E project
EYETS
SPS
CC
LS2
injector upgrade
cryogenics Point 4
dispersion
suppression
collimation
LS3
HL-LHC installation
8 TeV
13-14 TeV
14 TeV
Run III
cryolimit
interaction
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nominal
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Run I
2013
2014
Run II
2018
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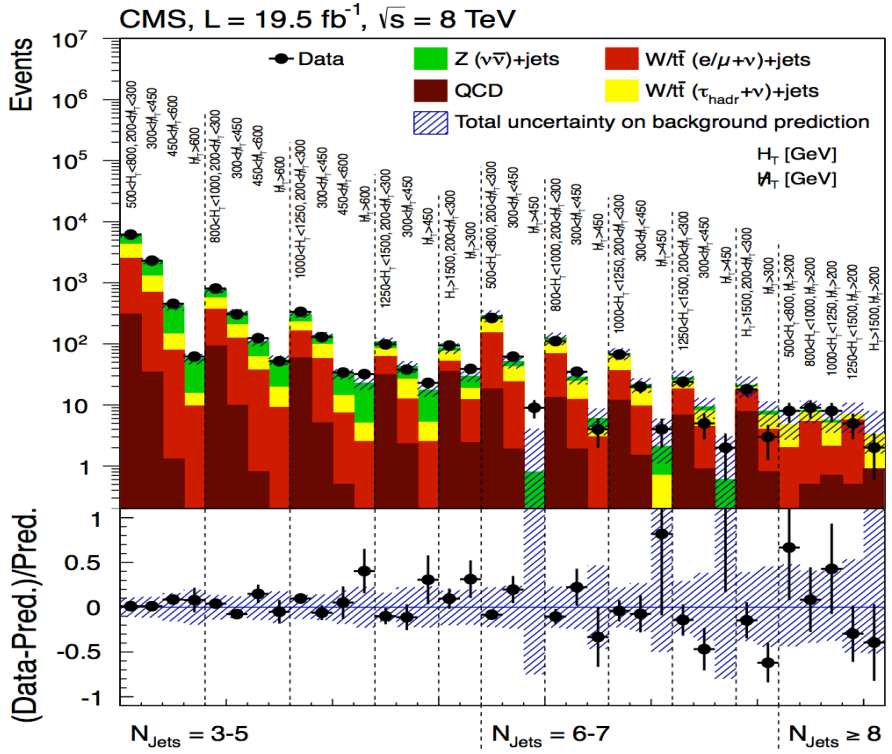
2020
2021
2022
2023
2024
2025
Run IV
radiation
damage
2 x nominal luminosity
nominal
luminosity 75%
experiment beam pipes
nominal luminosity
experiment upgrade
phrase 1
experiment upgrade phase 2
25 fb-1
100 fb-1
300 fb-1
3000 fb-1
0.75 10^34 cm^-2s^-1
50 ns bunch
high pile up ~40
1.5 10^34 cm^-2s^-1
25 ns bunch
pile up ~40
1.7-2.2 10^34 cm^-2s^-1
25 ns bunch
pile up ~60
~5(7.5!) 10^34 cm^-2s^-1
25 ns bunch
pile up ~140 - 200
50 ⇒ 25 ns

Run 1: Hadronic SUSY - Inclusive Search

- Multijet search for gluinos and light squarks
  - select events with large scalar sum momenta and missing E_T containing only jets, or photons plus jets
  - 7 TeV analysis was expanded for 8 TeV to include directly study high jet multiplicity

- Significant LPC collaboration

Collaborators: Baylor, Carnegie-Mellon, Colorado, Florida International, Florida State, Hamburg-DESY, UI Chicago, Iowa State, Notre Dame, UC Riverside, Rutgers, Rockefeller, Virginia

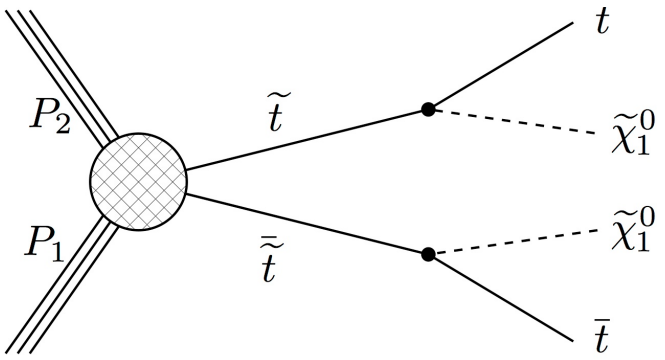


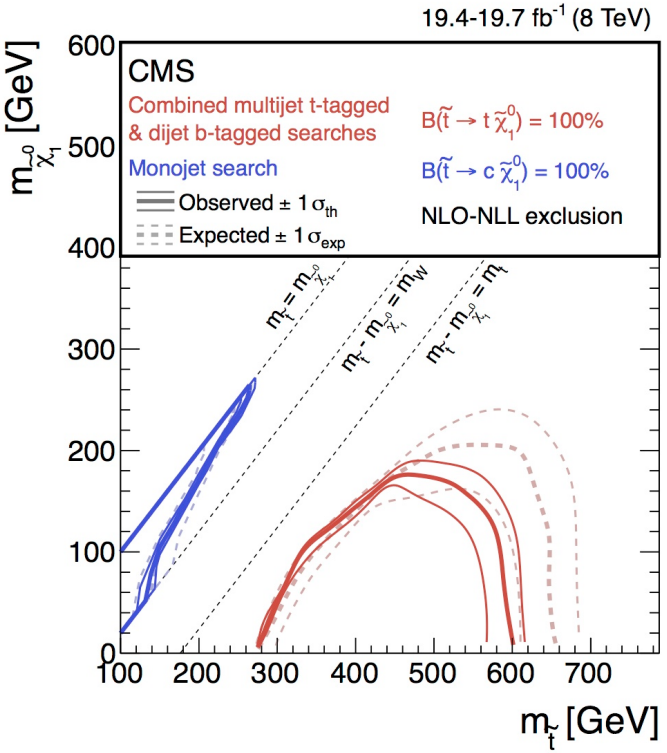
Fermilab

Run 1: Hadronic SUSY - Stop Search

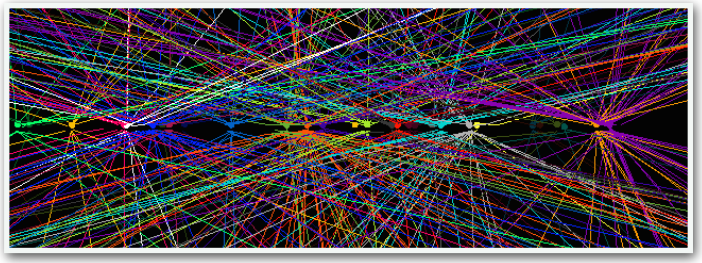
- Search for direct stop production
  - select events with top-tagged jets
  - require large missing momentum
  - dominant background from SM ttbar production

- Again, significant collaboration with LPC institutions



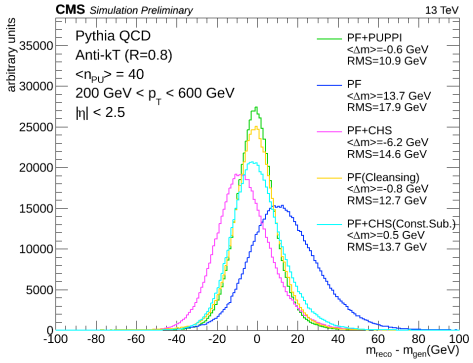


LHC Run II and beyond - “boosted jets”

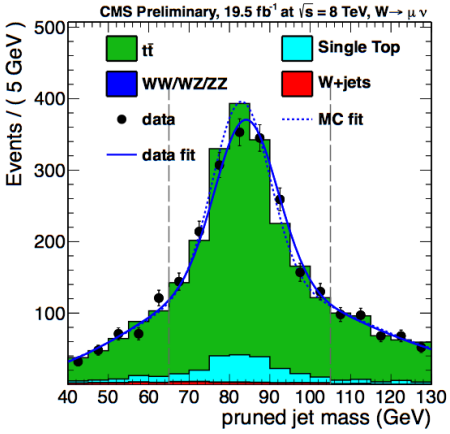


coherent, **per particle**, treatment of pileup improves performance of all CMS reconstruction **[PUPPI]**

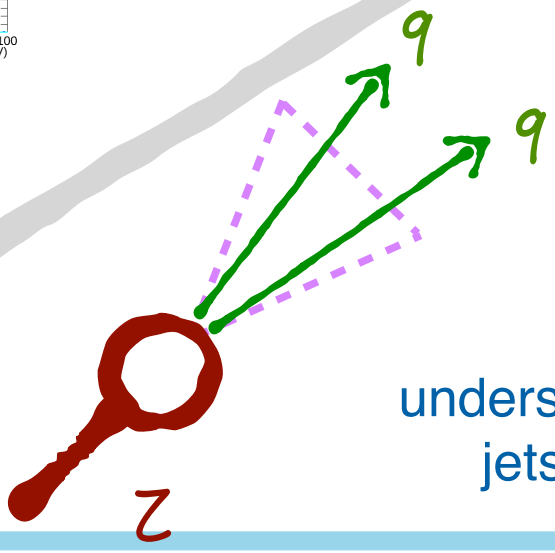
more energy
more boost



characterizing radiation



more collisions
more pileup



understanding structure of very energetic jets increases reach of LHC searches

Run 1 Papers by Lead Author

- **Jacob Anderson (4) with K. Mishra, F. Yang, J. Berryhill**

1. **HIN** Serguei Chatrchyan et al. [CMS Collaboration], "Indications of suppression of excited Y states in PbPb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV," Phys. Rev. Lett. 107, 052302 (2011) [arXiv:1105.4894 [nucl-ex]].
2. **SMP** S. Chatrchyan *et al.* (CMS Collaboration), "Measurement of the sum of WW and WZ production with W+dijet events in pp collisions at TeV", *Eur. Phys. J. C***73**, 2283 (2013) [arXiv:1210.7544 [hep-ex]].
3. **SMP** S. Chatrchyan *et al.* (CMS Collaboration), "Study of the dijet invariant mass distribution in W plus jets events produced in pp collisions at TeV", *Phys. Rev. Lett.* **109**, 251801 (2012) [arXiv:1208.3477 [hep-ex]].
4. **HIG** S. Chatrchyan *et al.* (CMS Collaboration), "Search for a standard-model-like Higgs boson with a mass of up to 1 TeV at the LHC", Eur. Phys. J. C73, 2469 (2013).

- **Jeff Berryhill (5) with K. Mishra and others**

1. **SMP** Measurement of the inclusive W and Z production cross sections in pp collisions at 7 TeV with the CMS experiment , S. Chatrchyan et al. (CMS Collaboration), JHEP 10 (2011) 132.
2. **SMP** Measurements of inclusive W and Z cross sections in pp collisions at 7 TeV, S. Chatrchyan et al. (CMS Collaboration), JHEP 01 (2011) 080.
3. **EXO** Search for massive resonances in dijet systems containing jets tagged as W or Z boson decays in pp collisions at 8 TeV S. Chatrchyan et al. (CMS Collaboration), JHEP 08 (2014) 173 (2013).
4. **SMP** A search for and production and constraints on anomalous quartic gauge couplings in pp collisions at 8 TeV S. Chatrchyan et al. (CMS Collaboration), Phys. Rev. D90 (2014) 032008.
5. **EXO** Search for a boson decaying to a bottom quark and a top quark in pp collisions at = 7 TeV, S. Chatrchyan et al. (CMS Collaboration), Phys. Lett. B718 (2013) 1229

Run 1 Papers by Lead Author (cont.)

- **Kevin Burkett (1) with Sergo Jindariani**

1. **POG** Description and performance of track and primary vertex reconstruction with the CMS tracker", JINST 9 (2014) 10, P10009.

- **Joel Butler (1)**

1. **BPH** Bs-->mumu joint paper fwith LCHB, submitted to Nature.

- **Vasu Chetluru (3) with Vivian O'Dell**

1. **SMP** Measurement of the triple-differential cross section for photon + jets production in proton-proton collisions at TeX = 7 TeV, JHEP 1406 (2014) 009
2. **SMP** Measurement of the Differential Cross Section for Isolated Prompt Photon Production in pp Collisions at 7 TeV, Phys. Rev. D 84, 052011 (2011)
3. **SMP** Measurement of the Isolated Prompt Photon Production Cross Section in pp Collisions at sqrt(s) = 7 TeV, Phys.Rev.Lett.106:082001,2011

Run 1 Papers by Lead Author (cont.)

• Daniel Elvira (2)

1. **SUS** Search for New Physics with Jets and Missing Transverse Momentum in pp collisions at 7 TeV (CMS Collaboration), J. High Energy Phys. 08 (2011) 155.
2. **SUS** Search for Supersymmetry in pp Collisions at 7 TeV in Events with Two Photons and Missing Transverse Energy, (CMS Collaboration) PRL 106 (2011) 211802.

• Yanyan Gao (6) with K. Burkett and S. Jindariani

1. **HIG** Search for the standard model Higgs boson in the H to ZZ to $2l2\nu$ channel in pp collisions at $\sqrt{s}$ = 7 TeV, published in J. *High Energy Physics. 03(2012) 040.*
2. **HIG** Search for the standard model Higgs boson decaying to a W pair in the fully leptonic final state in pp collisions at $\sqrt{s}$ = 7 TeV, *Phys. Lett. B 710(2012) 91-113.*
3. **HIG** Study of the mass and spin-parity of the Higgs boson candidate via its decays to Z boson pairs", arXiv:1212.6639
4. **HIG** Observation of a new boson at a mass of 125 GeV with the CMS experiments", Phys. Lett. B716, 30-61
5. **HIG** A New boson with a mass of 125 GeV observed with the CMS experiments at the Large Hadron Collider", Science 388, 6114(2012) 1569-1575
6. **HIG** On the spin and parity of a single produced resonance at the LHC", Phys. Rev. D86, 095031(2012)

• Lindsey Gray (1) with J. Berryhill

1. **HIG** search for a light standard model Higgs decaying to a photon and a Z boson, Phys. Lett. B 726 (2013) 587
2. **POG** Performance of electron reconstruction and selection with the CMS detector at sqrt(s)=8TeV , submitted to JINST.

Run 1 Papers by Lead Author (cont.)

- **Daryl Hare (1) with R. Cavanaugh and D. Elvira**

1. **SUS** 3rd generation squark searches in all hadronic final state (CMS Collaboration, in CWR now,

- **Robert Harris (7) with K. Kousouris and D. Elvira**

1. **EXO** 3 pb^{-1} @ 7 TeV: *Search for Dijet Resonances in 7 TeV pp Collisions at CMS*, Phys.Rev.Lett.105 (2010) 211801
2. **EXO** 1 fb^{-1} @ 7 TeV: *Search for Resonances in the Dijet Mass Spectrum from 7 TeV pp Collisions at CMS*, Phys.Lett. B704 (2011) 123-142
3. **EXO** 5 fb^{-1} @ 7 TeV: *Search for narrow resonances and quantum black holes in inclusive and b-tagged dijet mass spectra from pp collisions at sqrt(s) = 7 TeV*, JHEP 01 (2013) 013,
4. **EXO** 4 fb^{-1} @ 8 TeV: *Search for narrow resonances using the dijet mass spectrum in pp collisions at sqrt(s) = 8 TeV*, Phys. Rev. D 87 (2013) 114015
5. **EXO** 20 fb^{-1} @ 8 TeV:, Search for resonances and quantum black holes using dijet mass spectra in proton-proton collisions at sqrt(s)=8 TeV, iv:1501.04198 , Accepted by PRD.
6. **EXO** Search for pair-produced dijet resonances in four-jet final states in *pp* collisions at $s\sqrt{}$=7 TeV, Phys. Rev. Lett. 110, 141802 (2013).
7. **POG** Determination of Jet Energy Calibration and Transverse Momentum Resolution in CMS , JINST 6 (2011) P11002.

- **Jim Hirschauer (3) with R. Harris and D. Elvira**

1. **SUS** Search for stealth supersymmetry in events with jets, either photons or leptons, and low missing transverse momentum in pp collisions at 8 TeV, CMS Collaboration, submitted to PLB (2014); arXiv:1411.7255.
2. **SUS** Search for supersymmetry in events with photons and low missing transverse energy in pp collisions at sqrt(s) = 7 TeV, CMS Collaboration, Phys. Lett. B 719 42 (2012); arXiv:1210.2052.
3. **EXO** Search for quark compositeness with the dijet centrality ratio in pp collisions at sqrt(s) = 7 TeV, CMS Collaboration, Phys. Rev. Lett. 105, 262001 (2010); arXiv:1010.4439.

Run 1 Papers by Lead Author (cont.)

- **Ben Hooberman (5) with V. Martinez and J. Linacre**

1. **SUS** Search for Physics Beyond the Standard Model in Opposite-sign Dilepton Events at sqrt(s) = 7 TeV", JHEP 6 (2011) 26
2. **SUS** Search for electroweak production of charginos, neutralinos, and sleptons using leptonic final states n pp collisions at √s = 8 TeV, JHEP 11 (2012) 147.
3. **SUS** Search for physics beyond-the-standard model in events with a Z boson, jets, and missing transverse energy in pp collisions at √s = 7 TeV, Phys. Lett. B716 (2012) 260-284
4. **SUS** Search for new physics in events with opposite-sign leptons, jets, and missing transverse energy in pp collisions at √s = 7 TeV, Phys. Lett. B718 (2013) 815-840
5. **SUS** Search for top-squark pair production in the single-lepton final state in pp collisions at sqrt(s) = 8 TeV", Eur. Phys. J C73 (2013) 2677

- **Sergo Jindariani (5) with Y. Gao and K. Burkett**

1. **HIG** Constraints on the spin-parity and anomalous HVV couplings of the Higgs boson in proton collisions at 7 and 8 TeV", accepted by PRD.
2. **HIG** Measurement of Higgs boson production and properties in the WW decay channel with leptonic final states", JHEP 1401 (2014) 096.
3. **SMP** Measurement of W+W- and ZZ production cross sections in pp collisions at $\sqrt{s}$=8 TeV", Phys. \ Lett. \ B721 (2013) 190-211.
4. **HIG** Search for the standard model Higgs boson decaying into W+W- in fully leptonic state in pp collisions at √s = 7 TeV", Phys. Lett. B710, 91-113(2012)
5. **HIG** Measurement of WW production and search for the higgs boson in pp collisions at Vs = 7 GeV", Phys. Lett. B 699 (2011) 25-47, preprint at arXiv:1102.5429

Run 1 Papers by Lead Author (cont.)

- **Keti Kaadze (2) with Kevin Pedro**

1. **EXO** Search for third generation leptoquarks and top squarks, Physics Letters B 739, 229 (2014)
2. **EXO** Search for neutral MSSM Higgs bosons decaying to a pair of tau leptons in pp collisions, JHEP10(2014)160

- **Jacob Linacre (3) with Oliver Gutsche**

1. **TOP** Measurements of t t-bar spin correlations and top-quark polarization using dilepton final states in pp collisions at sqrt(s) = 7 TeV" Phys. Rev. Lett. 112 (2014) 182001
2. **TOP** "Measurements of the t t-bar charge asymmetry using the dilepton decay channel in pp collisions at sqrt(s) = 7 TeV" JHEP 04 (2014) 191
3. **EXO** Search for heavy, top-like quark pair production in the dilepton final state in pp collisions at $\sqrt{s}$ = 7 TeV," Phys.Lett. B716 (2012) 103–121

- **Verena Martinez Outschoorn (1) with B. Hooberman**

1. **SUS** Search for electroweak production of charginos, neutralinos, and sleptons using leptonic final states in pp collisions at sqrt(s) = 8 TeV", Eur. Phys. J. C74 (2014) 9, 3036

- **Dave Mason (1) with Daniel Elvira**

1. **SUS** Search for new physics in events with photons, jets, and missing transverse energy in pp collisions at 7 TeV (CMS Collaboration), J. High Energy Phys. 03 (2013) 111.

- **Steve Mrenna (1)**

1. **SUS** Interpretation of Searches for Supersymmetry, Phys. Rev. D 88, 052017 (2013)

Run 1 Papers by Lead Author (cont.)

- **Rafael Lopes De Sa (2) with Sergo Jindariani**

1. **SMP** Study of Vector Boson Scattering and Search for New Physics in Events with Two Same-Sign Leptons and Two Jets, PhysRevLett.114.051801.
2. **SMP** Measurement of the W+W− cross section in pp collisions at √s = 8 TeV and limits on anomalous gauge couplings", in CWR

- **Niki Saoulidou (1)**

1. **SMP** Measurement of the differential dijet production cross section in proton-proton collisions at √s=7 TeV, Phys. Lett. B 700 (2011) 187–206

- **Seema Sharma (2) with Daniel Elvira**

1. **SUS** Search for new physics in the multijet and missing transverse momentum final state in proton-proton collisions at 8 TeV (CMS Collaboration), J. High Energy Phys. 06 (2014) 055.
2. **SUS** Search for New Physics with Jets and Missing Transverse Momentum final state in pp collisions at sqrt(s) = 7 TeV", PRL 109, 171803 (2012)

- **Lenny Spiegel (1)**

1. **EXO** Search for contact interactions in μ + μ − events in pp collisions at s √=7 TeV , Phys. Rev. D 87, 032001 – Published 1 February 2013

Run 1 Papers by Lead Author (cont.)

- **Slawek Tkaczyk (12) with EWK team**

1. **SMP** Study of vector boson scattering and search for new physics in events with two same-sign leptons and two jets CMS Collaboration (Vardan Khachatryan (Yerevan Phys. Inst.) et al.). Oct 23, 2014. 27 pp. Published in Phys.Rev.Lett. 114 (2015) 051801
2. **HIG** Search for invisible decays of Higgs bosons in the vector boson fusion and associated ZH production modes CMS Collaboration (Serguei Chatrchyan (Yerevan Phys. Inst.) et al.). Apr 4, 2014. 35 pp. Published in Eur.Phys.J. C74 (2014) 2980
3. **SMP** Measurement of inclusive W and Z boson production cross sections in pp collisions at s√ = 8 TeV CMS Collaboration (Serguei Chatrchyan (Yerevan Phys. Inst.) et al.). Feb 4, 2014. 17 pp. Published in Phys.Rev.Lett. 112 (2014) 191802
4. **SMP** Measurement of the muon charge asymmetry in inclusive pp→W+X production at s√= 7 TeV and an improved determination of light parton distribution functions CMS Collaboration (Serguei Chatrchyan (Yerevan Phys. Inst.) et al.). Dec 21, 2013. 33 pp. Published in Phys.Rev. D90 (2014) 3, 032004
5. **SMP** Measurement of the W+W− Cross section in pp Collisions at s√=7 TeV and Limits on Anomalous WWγ and WWZ couplings CMS Collaboration (Serguei Chatrchyan (Yerevan Phys. Inst.) et al.). Jun 5, 2013. Published in Eur.Phys.J. C73 (2013) 10, 2610
6. **SMP** Forward-backward asymmetry of Drell-Yan lepton pairs in pp collisions at s√=7 TeV CMS Collaboration (Serguei Chatrchyan (Yerevan Phys. Inst.) et al.). Jul 2012. 29 pp. Published in Phys.Lett. B718 (2013) 752-772
7. **SMP** Measurement of the electron charge asymmetry in inclusive W production in pp collisions at s√=7 TeV CMS Collaboration (Serguei Chatrchyan (Yerevan Phys. Inst.) et al.). Jun 2012. 27 pp. Published in Phys.Rev.Lett. 109 (2012) 111806
8. **SMP** Measurement of the Rapidity and Transverse Momentum Distributions of Z Bosons in pp Collisions at s√=7 TeV CMS Collaboration (Serguei Chatrchyan (Yerevan Phys. Inst.) et al.). Oct 2011. 21 pp. Published in Phys.Rev. D85 (2012) 032002

Run 1 Papers by Lead Author (cont.)

10. **SMP** Measurement of the weak mixing angle with the Drell-Yan process in proton-proton collisions at the LHC CMS Collaboration (Serguei Chatrchyan (Yerevan Phys. Inst.) et al.). Oct 2011. 41 pp. Published in Phys.Rev. D84 (2011) 112002
11. **SMP** Measurement of the lepton charge asymmetry in inclusive W production in pp collisions at s√=7 TeV CMS Collaboration (Serguei Chatrchyan (Yerevan Phys. Inst.) et al.). Mar 2011. 28 pp. Published in JHEP 1104 (2011) 050
12. **SMP** The WLWL Scattering at the LHC: Improving the Selection Criteria K. Doroba (Warsaw U.), J. Kalinowski (Warsaw U. & Hamburg U.), J. Kuczmarski, S. Pokorski, J. Rosiek (Warsaw U.), M. Szleper (Warsaw, Inst. Nucl. Studies), S. Tkaczyk (Fermilab). Jan 2012. 25 pp. Published in Phys.Rev. D86 (2012) 036011

- **Nhan Tran (3)**

1. **SMP** Studies of jet mass in dijet and W/Z + jet events", JHEP 1305 (2013) 090.
2. **SMP** Identification techniques for highly boosted W bosons that decay into hadrons", JHEP 1412 (2014) 017
3. **EXO** Search for massive resonances decaying into pairs of boosted bosons in semileptonic final states at sqrt(s) = 8 TeV", arXiv:1405.3447 (2014)